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STRICTURE FORMATION
IN ANASTOMOSES AND MUCOSAL
DEFECTS IN THE ESOPHAGUS

An experimental study in the piglet.

SVEN ÅKE KORNFÄLT

FROM THE DEPARTMENT OF PEDIATRIC SURGERY (DIRECTOR:
ASS. PROF. LUDVIG OKMIAN), THE UNIVERSITY HOSPITAL,
LUND, SWEDEN.

Sven Åke Kornfält

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IN THE ESOPHAGUS. AN EXPERIMENTAL STUDY IN THE PIGLET.

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- II KORNFÄLT, S.Å., OKMIAN, L. & JONSSON, N.:
Everted and End-on Esophageal Anastomosis in the Piglet. Z Kinderchir 12: 304-312, 1973.
- III KORNFÄLT, S.Å., OKMIAN, L. & JONSSON, N.:
Healing of Esophageal Anastomosis after Release of Tension by Myotomy. Z Kinderchir 12: 1973. In press.
- IV KORNFÄLT, S.Å., OKMIAN, L. & JONSSON, N.:
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- V KORNFÄLT, S.Å., OKMIAN, L. & JONSSON, N.:
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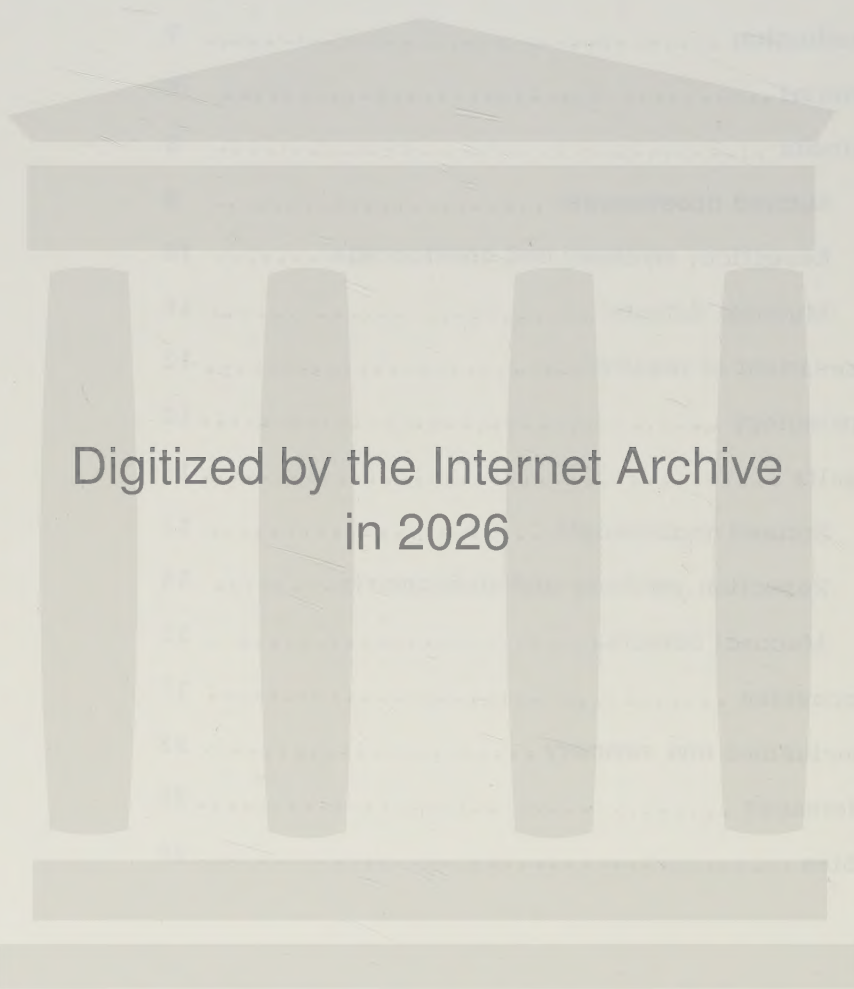
Reference to these papers will be made by the numerals I - VI

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C O N T E N T S

Introduction	7
Material	8
Methods	8
Sutured anastomosis	8
Resection, myotomy and anastomosis	10
Mucosal defects	10
Assessment of results	12
Terminology	12
Results	13
Sutured anastomosis	13
Resection, myotomy and anastomosis	14
Mucosal defects	15
Discussion	17
Conclusions and summary	23
References	25
Tables	29



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INTRODUCTION

HAIGHT (7) in 1941 performed the first primary anastomosis in esophageal atresia where the patient survived the procedure. Leakage developed at the anastomosis however and the patient was left with a stricture. Complications of anastomosis in the form of stricture are still a serious threat and are reported as occurring in 8 - 75 % (Table I).

Different techniques of anastomosis have been recommended as reducing the frequency of stricture after operation for esophageal atresia. The telescopic anastomosis described by HAIGHT is, together with single layer end-to-end and two layer end-to-end anastomoses, the most commonly used according to a collecting review (HOLDER, CLOUD, LEWIS & PILLING, 12). Experimental trials with another esophageal anastomosis technique have been carried out by HERTZLER & TUTTLE (10) and MYERS (24), who used everted anastomoses in the dog with good results. OKMIAN, LIVADITIS, BJÖRCK & IVEMARK (25) totally avoided leakage with a suture-less clamp anastomosis technique in the piglet but all anastomoses healed with obliteration of the lumen.

Experiments to study the localization of the stricture process have been carried out in the piglet by LIVADITIS, OKMIAN, BJÖRCK & IVEMARK (17) who from their results of selective suture of the layers of the esophageal wall drew the conclusion that there was "a relationship between defective mucosal contact or mucosal damage and stricture formation". LIVADITIS (19) suggested that the explanation might be that mucosal damage led to local infection and proliferative fibrosis.

Although collective clinical experience adds up to 30 years' material and several experimental studies have highlighted the problems, different reasons for the high frequency of stricture formation are still matters for debate.

This series of studies deals with healing in the different tissue layers of the esophagus mainly with a view to elucidating the localization and pathogenesis of the stricture process.

M A T E R I A L

93 piglets of Swedish Landrace were used as experimental animals. Their ages varied between 2 - 3 weeks and weight between 2.8 - 6.4 kg. 10 piglets died during operation from malignant hyperthermia (HALL et al, 8, 9) or other complications of anaesthesia and have not been included in the material.

M E T H O D S

The procedures were carried out under anaesthesia with Fluothane nitrous oxide and oxygen. The animals were intubated and ventilated artificially with an Engström ventilator.

The procedures were performed on the cervical or thoracic esophagus. The cervical esophagus was exposed between the larynx and sternum. The thoracic esophagus was exposed via the pleural cavity through a right sided thoracotomy. The dissections were performed carefully, making sure that no visible blood vessels or nerves to the esophagus were divided.

The experiments comprised three main groups, one group in which different sutured anastomoses were performed, a second in which sutured anastomoses were made after resection and release myotomy, and a third group in which different types of mucosal defect were created. The number of animals in the different groups is shown in Table II.

SUTURED ANASTOMOSES

Seven types of anastomosis were performed, comprising the whole esophageal wall (II, IV), only the muscular layers (I, IV) or only the mucosal layers (IV) (Fig.1). All these procedures were carried out on the cervical esophagus and in all cases 9 - 10 interrupted sutures were used, using black braided silk on an atraumatic needle.

T h e w h o l e e s o p h a g e a l w a l l

After the esophagus had been divided transversely, the anastomoses were performed either with sutures which everted the edges or with an end-on technique, that is to say, the edges were brought together as perfectly as possible without bringing about either inversion or eversion (II, IV).

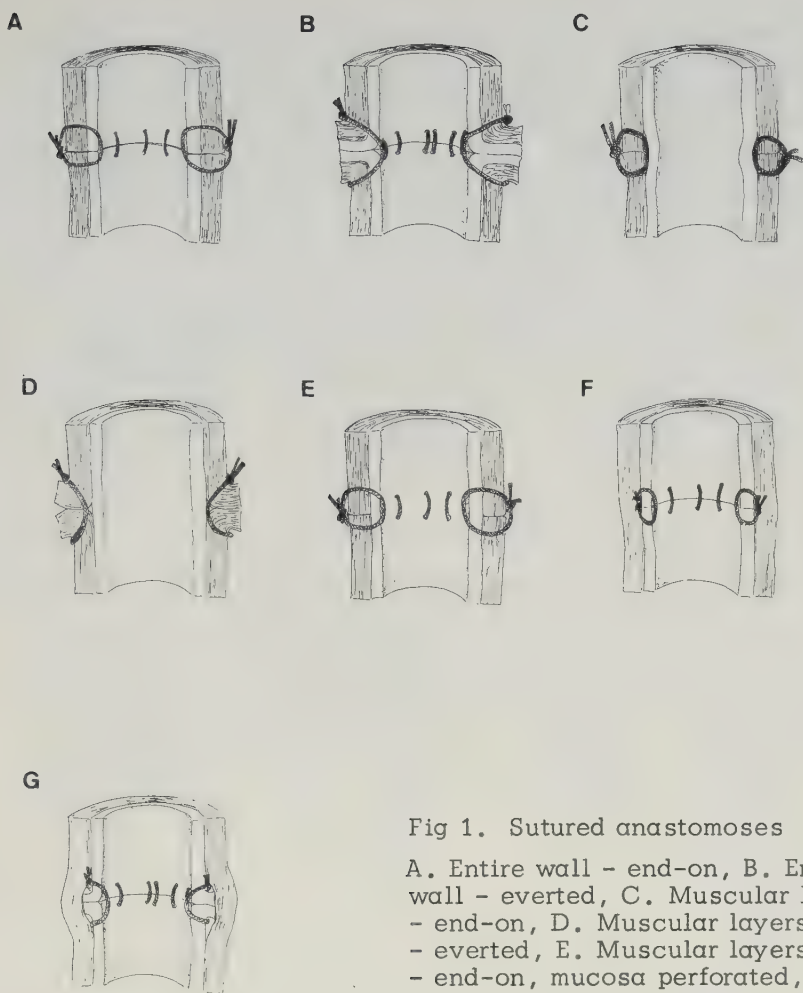


Fig 1. Sutured anastomoses

A. Entire wall - end-on, B. Entire wall - everted, C. Muscular layers - end-on, D. Muscular layers - everted, E. Muscular layers - end-on, mucosa perforated, F. Mucosal layers - end-on, G. Mucosal layers - everted.

The muscular layers

The muscular layers were divided circularly and three types of anastomosis of the muscular layers performed; with eversion of the edges (IV), with an end-on technique without including the mucosa (I), or with sutures that included the mucosa, passing into the lumen. In the last case a small opening in the mucosa was also made to permit inspection of the position of the sutures in the lumen.

The mucosal layers

The mucosa was exposed through a small longitudinal incision in the muscular layers and then divided circularly, after which anastomosis of the mucosa was performed either with everting sutures or with an end-on technique. Following this, the longitudinal incision in the muscular layers was closed (IV).

RESECTION, MYOTOMY AND ANASTOMOSIS

These procedures were performed on the thoracic esophagus. A segment 21 mm long, standardized by a clamp, was resected, giving a gap large enough to make direct anastomosis impossible. After a circular myotomy had been carried out on the proximal segment 2 cm above the resected edge, the tension was reduced and an end-to-end anastomosis could be performed with interrupted 6/0 silk sutures (Fig.2). In one group of experimental animals a transanastomotic catheter was inserted, while in another group no such catheter was used (III).

MUCOSAL DEFECTS

The mucosa was exposed through a small incision in the muscular layers after which four different mucosal defects were produced (Fig.3): circular division of the mucosa, bringing about a gap between the mucosal ends due to retraction (V), excision of a 5 mm long mucosal cylinder (V), resection of a rectangular shaped portion of mucosa, leaving a 1 mm wide, 10 mm long mucosal bridge (VI), excision of two rectangular portions of mucosa leaving two mucosal bridges each 1 x 10 mm (VI). In those cases where the mucosa was divided, one group of animals was left without any further measure, while in another group an intraluminal catheter was passed. In a third group the mucosal ends were everted into the muscle cylinder and secured with sutures.

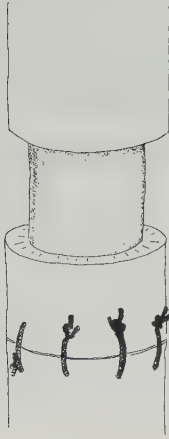


Fig 2. Myotomy and anastomosis

A



B



C



D

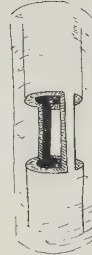


Fig 3. Division or resection of mucosa

- A. Division or resection of a cylinder
- B. Division, eversion and fixation
- C. Resection of a rectangle
- D. Resection of two rectangles

ASSESSMENT OF RESULTS

The piglets were observed when they ate and any swallowing difficulties were recorded. The weight at operation and at death was noted (VI).

In a small series swallowing action was studied radiographically postoperatively (V).

The animals were killed with an overdose of pentothal and at autopsy the preparation was examined carefully and photographed. It was also filled with Urografin 60 % to a pressure of 25 cm H₂O. Radiography of the preparation was carried out at this standardized degree of filling (RSFD). The width of the esophageal lumen above (I, II), at the point of and below the procedure site was measured. All the preparations were fixed in formalin and examined microscopically.

TERMINOLOGY

RSFD denotes radiogram carried out at a standardized filling degree of 25 cm H₂O.

Waist denotes the finding on RSFD of a slight narrowing of the lumen at the site of the procedure in the esophagus but where the reduction in luminal width does not amount to more than double the thickness of the esophageal wall.

Stricture denotes a more pronounced narrowing of the esophageal lumen at the site of the procedure visible by RSFD.

Atresia denotes total obliteration of the lumen as demonstrated by filling and RSFD.

Muscular layers comprise the adventitia, muscularis propria and a part of the submucosa.

Mucosal layers comprise the remainder of the esophageal wall i.e. the remaining part of the submucosa, the mucosal stroma, muscularis mucosae and surface epithelium.

RESULTS

SUTURED ANASTOMOSES

The whole esophageal wall (II)

With everting sutures. After two weeks the four animals began to show swallowing difficulties. They survived the intended observation time but failed to gain weight. Autopsy four weeks postoperatively showed pronounced stricture at the site of the anastomosis. RSFD demonstrated stricture formation with reduction of the lumen to half of that below the site of anastomosis. Microscopic examination revealed marked fibrosis in the muscular layer and in the adventitia together with epithelial inclusions in the submucosa.

With an end-on technique. The four piglets in this group showed no swallowing difficulties and at autopsy 3 - 4 weeks postoperatively, no strictures were found. On RSFD the site of anastomosis was apparent as a waist, but the width of the lumen at the anastomosis was the same as that below. Microscopic examination showed fibrosis in the muscular layer and adventitia.

Muscular layers (I, IV)

With everting sutures. All four piglets ate well, showed no swallowing difficulties and gained in weight. At autopsy 48 - 49 days postoperatively, the site of the anastomosis could be made out as a slight narrowing or only by the presence of remaining sutures. RSFD showed either a waist or no effect on the lumen at all. Microscopic examination showed that the divided segments of the muscular layer had become united by zones of collagen rich scar tissue with a slight inflammatory reaction.

With end-on technique. In two piglets sacrificed at 36 and 48 days respectively postoperatively the site of anastomosis could be discerned by RSFD as a waist. One piglet which died of enterocolitis 163 days postoperatively and the other three, which were fed for 178 - 200 days until they weighed about 100 kg, showed no strictures at autopsy. Microscopic examination revealed an increased fibrosis in the muscular layer in all the specimens.

End-on technique with sutures perforating the mucosa. No strictures could be seen at autopsy. The piglets were sacrificed after 36, 62 and 178 to 200 days respectively postoperatively. They all ate without difficulty and increased in weight. RSFD showed waists in the specimens from the two piglets sacrificed early

while the anastomosis site in the remaining four specimens could not be recognized. Microscopic examination showed increased fibrosis in the mucosa and in the muscular layer.

The mucosal layers (IV)

With everting technique. The four piglets in this group ate well during the first week but then began to show swallowing difficulties and gained weight very slowly. At autopsy 26 days postoperatively strictures were seen in all the specimens. RSFD showed strictures with a reduction in the lumen of up to 50 %. Microscopic examination showed that the surface was covered by a thin epithelium under which small epithelial inclusions were found.

With end-on technique. All four piglets in this group ate well and increased in weight. At autopsy 28 - 30 days postoperatively a slight narrowing was found on careful examination of one specimen while the remaining three had healed without narrowing of the lumen. RSFD showed a 50 % reduction in the lumen of the one specimen. The surface was found on microscopic examination to be covered by a squamous epithelium of normal or slightly reduced thickness.

RESECTION, MYOTOMY AND ANASTOMOSIS (III)

Without transanastomotic catheter. Seven piglets were used. Three piglets sacrificed after 1 - 3 days were found to have necrotic areas in the mucosa along the anastomosis. Serious swallowing difficulties developed in the four other animals, which had to be sacrificed 16 - 28 days postoperatively to forestall death from starvation. Autopsy showed a healed anastomosis without sign of leakage but with pronounced stricture formation localized to the site of anastomosis. The amuscular region above the anastomosis showed no narrowing of the lumen. On RSFD the lumen in the region of the anastomosis was found to be obliterated without a functioning communication between the two halves. Microscopic examination showed that the lumen of the two blind ends was covered by a normal or somewhat thinned squamous epithelium.

With transanastomotic catheter. One of the piglets which had a catheter for only 15 days developed atresia. The remaining four which had a catheter for 22 - 48 days all healed with strictures but with a functioning lumen. Microscopic examination showed that the anastomosis was covered by epithelium in three of the piglets while one still had an epithelial defect in the region of the anastomosis.

MUCOSAL DEFECTS

Circular division of the mucosa

Without transanastomotic catheter (V). The nine piglets ate satisfactorily for the first few days but thereafter developed swallowing difficulties and began to lose weight.

X-ray examination of the esophagus with contrast medium carried out one week and two weeks postoperatively showed increasing narrowing of the lumen at the site of the procedure. Two weeks postoperatively the lumen was to all intents and purposes totally obliterated.

At autopsy 4 days postoperatively the edges of the mucosal ends were found drawn together with obvious reduction in the lumen and at 8 days postoperatively the lumen was appreciably constricted.

At autopsy 26 - 30 days postoperatively the mucosa had healed as two separate sacs. The two animals which had gastrostomies showed no connection at all between the sacs while the other two had a narrow fistulous connection through which however no fluid could be forced.

With transanastomotic catheter for up to 10 days (V). Four of the seven piglets were sacrificed immediately after the catheter had been taken out. The remainder were able to eat freely the first week but then showed swallowing difficulties.

Immediately following division the mucosal ends were retracted to produce a gap of 10 mm. 4 - 8 days postoperatively the gap had been reduced by a few mm. However the gap had begun to be bridged by migrating regenerating epithelium, which six days postoperatively covered half the denuded area. The three piglets which were allowed to live for 7 - 20 days after extubation showed at autopsy healing with obliteration of the lumen. RSFD showed atresia but on microscopic examination a small epithelialized fistula could be discerned in two of the preparations.

With transanastomotic catheter for 14 - 34 days (V). The six animals in this group were allowed to live for 29 - 97 days postoperatively and all showed healing with a functioning lumen, which on RSFD however showed varying degrees of stricture with reduction in the lumen of up to a maximum of 75 %. A soft regenerated mucous membrane covered the area of the original mucosal defect. Microscopically the mucosal layer was found to be replaced by scar tissue and covered by regenerated epithelium. No submucosal glands were seen.

Eversion of the mucosal ends (VI). The piglets could feed themselves but increased weight insignificantly. At autopsy 21 - 47 days postoperatively the remains of the everted mucosa could be made out but the gap was covered with a thin mucous membrane which on microscopic examination proved to be regenerated epithelium. RSFD revealed strictures with reduction of the lumen to 20 - 80 % of that below the operation site.

Excision of a mucosal cylinder (V)

One of the five piglets was sacrificed 3 days postoperatively. During the first 3 - 4 postoperative days the remaining four animals swallowed freely but thereafter began to show swallowing difficulties, became emaciated and were killed 12 - 21 days postoperatively. X-ray examination of the esophagus with contrast medium 6 and 12 days postoperatively showed commencing occlusion of the lumen. At autopsy the mucosa was found to have healed as two pouches which were also demonstrated by RSFD. Microscopic examination showed that the blindly ending lumen was covered by a squamous epithelium with submucosal glands, that is, not by regenerating epithelium. The mucosa had moved into the lumen and healed there causing occlusion.

Excision of rectangular portions of m u c o s a (VI)

With one remaining mucosal strip. All four piglets ate well and increased in weight. At autopsy 46 - 50 days postoperatively the mucosal defect was seen to have healed with a covering of even epithelium, partly of normal type, partly of a regenerated type. The lumen, which was constricted, was situated eccentrically on the side of the mucosal strip originally left. RSFD showed that the lumen was reduced by 60 - 90 %.

With two remaining mucosal strips. All four piglets ate without difficulty and increased normally in weight. At autopsy the mucosal defects were healed and a lesser constriction than in the preceeding group was noted, varying on RSFD between 15 - 50 %. The mucosal defects were covered partly by normal gland containing epithelium and partly by a regenerated thin epithelium without glands.

DISCUSSION

Factors which have been shown to influence the development of stricture after esophageal anastomoses are, according to SCHULTZ & CLATWORTHY (29), the type of anastomosis, tissue reaction to the suture material, infection, leakage and tension in the suture line. The operative technique has also been stated to be of significance for healing of the anastomosis (KOOP & VERHAGEN (13), POTTS (27)). Insufficient growth of the anastomosis in a rapidly growing individual has been found to be a significant factor in stricture development (II).

Several types of anastomosis have been used for operation of esophageal atresia. In a comprehensive american survey single layer end-to-end anastomosis was found to be the most commonly used, after which came HAIGHT's telescopic anastomosis and then two layers end-to-end anastomosis (HOLDER et al, 12). The highest frequency of strictures in this material judged by the need for dilatation, was after HAIGHT's method, (52 %), while after two layers end-to-end it was 40 % and single layer end-to-end, 36 %. On the other hand, CLOUD (3), in a series of anastomoses performed by the two layers end-to-end method had strictures in only 8 %. Even when one takes into consideration the differing definitions of stricture in the different series, the frequency of stricture with the same method of anastomosis varied so much that it is obvious that other factors play a decisive role in the development of stricture after esophageal anastomosis.

The significance of the suture material in the development of strictures in the esophagus of growing animals has been studied by SCHULTZ, RODRIQUES-PEREIRA & CLATWORTHY (28) who found that catgut gave more strictures than silk and that no stricture occurred after dacron and steel wire. The authors felt that they could not draw any conclusions from this because of the small size of the series. It is of interest in this connection to note that with sutureless anastomosis with a clamp in the piglet, pronounced strictures developed in all cases (OKMIAN et al, 25). Thus the suture material as such is thought to be of minor importance in the development of esophageal stricture.

On anastomosis of the divided esophagus, contamination of the row of sutures always takes place, not only during the procedure but also for a certain time afterwards via the suture tracts. The results (I) indicated that anastomotic inflammatory reaction and fibrosis, whether caused by the silk thread per se, by prolonged contamination through the suture tracts or by a combination of these factors, were insignificant in the development of anastomotic stricture.

Leakage at the anastomosis is accompanied by a high percentage of strictures (SCHULTZ et al, 29). LIVADITIS, OKMIAN & EKLÖF (16) found that of 6 patients that survived anastomotic leakage, 4 developed anastomotic stricture.

However, leakage always means also partial or total rupture of the anastomosis and defective contact between the tissues in the anastomosis.

In a considerable number of cases of esophageal atresia the anastomosis cannot be carried out without a certain tension in the suture line. SCHULTZ et al (29) established that 60 % of their anastomoses carried out with marked tension, by which they meant a gap of 2 1/2 - 3 cm, developed strictures. When no obvious tension was present in the suture line, stricture was found in only 10 %. After resection and anastomosis of the thoracic esophagus in piglets, mucosal necroses with subsequent mucosal defects in the line of the anastomosis were demonstrated in spite of release myotomy (III). The myotomy relaxed the tension in the muscular component of the anastomosis, but on the other hand put a strain on the mucosal component. The areas of necrosis and defects could also be related to tension in the anastomosis. They probably also reflect the course of events in healing under tension without release myotomy. It is a common experience that anastomosis rupture occurs more often if the suture line is exposed to tension. Partial or total rupture of the anastomosis in such a context might explain the high frequency of strictures.

Thus several factors are seen to be of significance in the genesis of anastomotic stricture in the esophagus. Tension and leakage together with subsequent defective tissue contact in the anastomosis appear to be important but the mechanism by which they bring about stricture is not altogether clear.

Procedures performed on the esophageal muscular layers, no matter what they are: myotomy (III, LIVADITIS et al, (17), LIVADITIS, RÅDBERG & ODENSJÖ (21)), myectomy (CARVETH, SCHLEGEL, CODE & ELLIS (2), KRALIK, VOJACEK & SKIBBE (14), LIVADITIS, BJÖRCK & KÄNGSTRÖM (18)) and suture anastomoses of different kinds (I, IV, LIVADITIS et al (17)) always heal without stricture. Even everted anastomosis, which when carried out on the mucosa or on the whole wall gave rise to pronounced stricture, gave no stricture when used on only the muscular layers (II, IV). Only when the mucosal layers were divided circularly and anastomosed alone or together with the whole wall could one demonstrate strictures in a definite percentage, irrespective of which anastomotic method was used. By elimination, the mucosa remained as that part of the esophageal wall to which stricture development could be localized. Moreover, mucosal defects, caused by tension in the anastomosis, were seen to be followed by stricture

formation (III). Thus interest was focussed on the mucosal layers and models for study were designed in which healing of mucosal defects could be selectively studied (V,VI).

The circularly divided mucosa (V) became retracted and left a gap between the ends. The gap healed with total obliteration of the lumen. The course of events was that the gap between the mucosal ends first became somewhat reduced. Even the lumina in the two ends were successively reduced, which on microscopic examination was found to depend upon a drawing in of the mucosa into the lumen. This process of healing, wound contraction, much and carefully studied in skin, has also been said, together with fibrous protein synthesis to predominate in healing in the esophagus (PEACOCK & VAN WINKLE, 26). Wound contraction in a tubular organ such as the esophagus means however a reduction in the luminal width, that is to say, stricture. The process showed itself to be a necessary link in the healing of mucosal defects (V). The severity of the stricture can be related to the extent of the mucosal defect in the anastomotic line. Obliteration of the lumen follows total separation, while the corresponding degree of stricture formation results from partial separation.

A specially developed operative technique with careful handling of the tissues and painstaking approximation of the ends provides conditions for healing with better tissue contact and fewer strictures. A lifelong experience has been expressed by WILLIS POTTS (27) in the following words: "To anastomose the ends of an infant's esophagus the surgeon must be as delicate and precise as a skilled watchmaker. No other operation offers a greater opportunity for pure technical artistry". In one series operated upon following POTTS principles CLOUD (3) also established a stricture frequency of only 8 %.

With an everted anastomosis a wide mucosal contact is obtained. The method is such that mucosal defects are avoided and no luminal narrowing is caused by the procedure itself. The wide anastomotic lumen in the small intestine has been reported on in several studies (for ref. see II). However, the stricture formation one sees without exception when use is made of the same method in the piglet's esophagus was attributed to rapid growth (II). Later studies gave little support for this supposition. The results of the studies mean however that everted anastomosis cannot be recommended in operation of esophageal atresia in contrast to what has been stated by HERTZLER & TUTTLE (10).

Better understanding of the localization and nature of the stricture process also found further application. Attempts to reduce the tension with a circular myotomy above the anastomosis in the piglet's thoracic esophagus led to the formation of a marked stricture or obliteration of the lumen at the anastomosis (III). With the same technique and on the same experimental animals LIVADITIS et al (21) measured a reduction in tension of 66 % but found that the anastomosis healed with decreased luminal width. The difference may depend on the fact that evaluation of the severity of the stricture is to a great extent dependent on the study technique used. On examination of preparations from animals killed a couple of days after operation (III) one finds necrotic areas in the mucosa both above and below the anastomosis. There is no doubt that the myotomy release technique gives complete relaxation at the anastomosis in the muscular layer, which loses its cranial attachment by the procedure. If however there is some tension in the anastomosis, as where a large gap is to be bridged, it will put a load particularly on the mucosal tissue. This increases the risk of ischaemic tissue necrosis and cutting out of the sutures, both resulting in separation of the mucosa. This process is probably the explanation for the obliteration of the esophageal lumen found in this series.

In addition to the experimental series already mentioned, circular myotomy intended to lengthen the esophagus has also been used for operation of newborn infants with esophageal atresia (LIVADITIS, 20), and for several years, adults operated for hiatus hernia (DAVIDSSON, 5). Clinical experience of circumferential division of the muscular layer points to the fact that a clear but limited lengthening of the esophagus is obtained, 2 - 3 cm in the adult (DAVIDSSON, 5). Experimentally, LIVADITIS et al (21) found it possible to carry out primary anastomosis after resections of up to 36 % of the thoracic esophagus, but they also mobilized the esophagus above and below the anastomosis. The advisability of doing this in infants with esophageal atresia can be debated. Without mobilization, only 2 cm could be bridged over, even experimentally (III).

Quite apart from how large the maximum actually is and irrespective of the risk of stricture, a gain of 2 cm in the length of the esophagus is crucial to whether a primary anastomosis is possible or not with esophageal atresia or after resection. Compared with interposition of colon, myotomy can be regarded as a small procedure, and even if the gap is bridged at the cost of a stricture, it can be treated later by dilatation or if necessary, resection. In contrast to interposed colon the esophagus after myotomy also functions with peristalsis. With esophageal atresia the proximal segment is however often short, but the myotomy in such cases can be performed on the cervical esophagus. It may also be

pointed out that in these cases the mucosa usually retracts itself 3 - 5 mm after division of the esophago-tracheal fistula and this unavoidably results in increased tension in the caudal mucosal edge at the anastomosis. The mucosa in the blind sac on the other hand is always in excess and can be stretched. Therefore with an anastomosis without myotomy the strain from tension becomes insignificant. The tension puts a strain mostly on the hypertrophied muscle of the blind sac and the hypotrophic distal end of the esophagus. Thus there are several reasons for recommending myotomy as a first measure to lengthen the esophagus. On the basis of the experimental results (III, V, VI), it is also suggested that in such cases a transanastomotic catheter be used for at least two weeks.

The effect of an intraluminal tube is interesting. The use of a transanastomotic catheter is on the whole a debatable subject and has been the object of dogmatic opinions. An intraluminal catheter during healing of an esophageal anastomosis is, according to PEACOCK & VAN WINKLE (26), deleterious to the basic mechanisms of wound healing. However, in the rabbit, a catheter through the esophageal anastomosis did not affect healing of the whole circumference. But in some segments the anastomosis was made weaker than those which healed in the absence of a catheter (BORGSTRÖM & LUNDH, 1). With studies in the dog on the other hand, no significant effect of an intraluminal tube through an esophageal anastomosis was found (MIDDLETON, HUMPHREY & FOSTER, 23).

Clinically far more important is the finding that that part of wound contraction that acts centripetally after mucosal division could be prevented by a catheter (V) and that a transanastomotic catheter prevented the otherwise unavoidable obliteration of the lumen after resection, myotomy and anastomosis under tension and facilitated healing with a functioning lumen (III).

Guided by this experimentally gained experience it is generally recommended that a transanastomotic tube be used in esophageal anastomoses and especially where mucosal defects can be expected as when the anastomosis is performed under tension. The catheter should be as wide as possible without actually stretching the relaxed esophagus. In fully developed newborn infants with esophageal atresia a no. 10 F. has been most often used, with regard to the nostril's and lower segment's calibres. A wider catheter is conceivable, especially if taken out in the submandibular region as described by TALBERT & HALLER (32), but has not yet been used in this clinic. On other occasions when mucosal defects can be expected, as with dilatation of strictures, the use of a sufficiently large catheter should be of advantage for healing with preservation of the lumen.

CONCLUSIONS AND SUMMARY

Healing in the different tissue layers of the esophagus were studied experimentally in 83 piglets with the intention of clarifying the localization and pathogenesis of the process of stricture formation.

Circular division of the mucosal layers alone without subsequent suturing led to healing of the defect with atresia.

Suturing with an everting technique led to stricture in all cases while with an end-on technique healing followed without stricture with only one exception.

Comparison of techniques in anastomosis involving the whole esophageal wall showed that an everting technique led to pronounced stricture while an end-on technique hardly affected the lumen.

Infection via the suture tracts was shown to be of little significance in stricture formation.

Circumferential myotomy in connection with anastomosis after resection made possible the bridging of large gaps. The release of tension in the muscular layers however was accompanied by increased tension on the mucosal edges at the anastomosis with poor mucosal contact and resulted in pronounced stricture.

Altogether these results showed that mucosal defects are the common factor in the different causes of stricture.

Healing of mucosal defects of known form and size was studied. It was established that stricture formation arose as a consequence of wound contraction. The severity of the stricture could be correlated to the size of the mucosal defect.

The effect of wound contraction could be reduced by the use of a transanastomotic catheter or by eversion of the mucosal edges, and provided conditions for complete epithelial regeneration.

Consequently it was shown that a transanastomotic catheter prevented obliteration occurring after circular division of the mucosal layers and also after circumferential release myotomy.

Guided by this experimentally gained experience it is recommended that a transanastomotic tube be used in esophageal anastomoses especially where mucosal defects can be expected, as when the anastomosis is performed under tension.

A specially developed operative technique with careful handling of the tissues and painstaking approximation of the mucosal ends are of the utmost importance for good operative results with the least possible frequency of strictures.

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Table I

Authors	Period	Survivors No.	% strictures	Type of anastomosis
Sulamaa 1951 (30)	1947-1950	7	71	End-to-side
Gross 1954 (6)	1943-1952	97	34	Haight
Swenson et al 1962 (31)	1951-1961	32	25	
Schultz & Clatworthy 1963 (29)	1951-1961	45	51	Two layers end-to-end
Holder et al 1964 (12)	1958-1962	200	52	Haight telescopic
		237	36	One layer end-to-end
		105	39	Two layers end-to-end
Martin 1965 (22)	1946-1964	54	37	Haight or single layer
Cozzi & Wilkinsson 1967 (4)	1959-1963	16	75	
	1963-1967	26	27	
Cloud 1968 (3)		76	8	Two layers end-to-end
Livaditis et al 1968 (15)	1952-1966	80	39	Single layer end-to-end
Holden & Wooler 1970 (11)	1939-1967	33	40	Haight telescopic

TABLE II

Type of procedure	Paper no	Number of piglets	No of piglets Result at RSFD					x)
			A	B	C	D	E	
ANASTOMOSIS								
Entire wall								
Everting sutures	II	4				4		
End-on technique	II	4			4			
Muscular layers								
Everting sutures	IV	4			4			
End-on technique	I	6		4	2			
End-on mucosal perf	I	6		4	2			
Mucosal layers								
Everting sutures	IV	4				4		
End-on technique	IV	4			3	1		
RESECTION, MYOTOMY AND ANASTOMOSIS								
No intraluminal tube	III	4						4
Intraluminal tube	III	8	3			4		1
MUCOSAL DEFECTS								
Circular division								
No intraluminal tube	V	9	5					4
Intraluminal tube								
0-10 days	V	7	4					3
Intraluminal tube								
14-34 days	V	6				6		
Eversion of mucosal ends	VI	4				4		
Excision of a mucosal cylinder	V	5	1					4
Excision of rectangular parts								
One remaining strip	VI	4				4		
Two remaining strips	VI	4				4		

- x) A. Autopsy before healing
 B. No luminal encroachment
 C. Waist
 D. Stricture
 E. Total luminal obliteration

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